TITLE

The acute and delayed effects of foam rolling duration on male athlete's flexibility and vertical jump performance.

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ABSTRACT

Foam rolling (FR) durations totaling ≤60 seconds per muscle are reported to acutely increase flexibility and vertical jump performance. However, limited research has investigated whether these benefits can outlast the inactive post-warmup preparatory period that typically separates warmups from the start of sporting competition. 11 male athletes (height 1.77 ± 0.09 m, body mass 78.0 ± 17.0 kg, age 22 ± 2 years) completed familiarization, followed by 3 experimental trials in a randomized and counterbalanced repeated measures crossover design. Trials commenced with 5 minutes of jogging, before ankle dorsiflexion range of motion (ADF-ROM), sit and reach (S&R), countermovement jump (CMJ), and squat jump (SJ) baseline testing. Participants then sat inactively for 10 minutes (control) or performed lower extremity FR totaling either 30 (30 FR) or 60 seconds (60 FR) that targeted four agonist-antagonist leg muscles. Testing was then repeated before and after a simulated inactive 15 minutes post-warmup preparatory period to establish the acute and delayed effects of FR on performance. A two-way repeated measures analysis of variance was used to identify any significant interaction effects between conditions (30 FR, 60 FR, control) and timepoint (baseline, acute, delayed). No significant condition x timepoint interaction effect was detected for the ADF-ROM ($f = 1.63$, $p = 0.19$), S&R ($f = 0.80$, $p = 0.54$), CMJ (($f = 0.83$, $p = 0.99$), or SJ ($f = 0.66$, $p = 0.99$). Therefore, FR totaling ≤60 seconds appears insufficient to enhance flexibility or vertical jump performance in male athletes.

KEY WORDS

Self-Myofascial Release, Post-Warmup Preparatory Period, Sit and Reach, Countermovement Jump, Squat Jump.

INTRODUCTION

Foam rolling (FR) applies external compression onto the fascia that surround musculotendinous units [1]. This external compression has been shown to alter muscle and tendon compliance, with superior joint flexibility [2–6] and performance across vertical jump, linear speed, and multidirectional agility testing reported in some studies following FR [7,8], but not always in others [9–12]. These potential benefits suggest that FR could complement sporting warmups, but little consensus exists on the minimal FR duration necessary to elicit any potential benefits [13]. Additionally, to enhance subsequent sports performance, the minimal duration of FR must elicit acute benefits that can outlast an inactive post-warmup preparatory period, which typically separates a warmup from the start or restart of competition [14]. Such inactive periods may impair sports performance by decreasing core and muscle temperature, with periods as short as 15 minutes significantly decreasing both muscle temperature and subsequent sports performance [14,15].

Multiple studies concur that FR durations totaling ≥90 seconds per muscle, which are typically performed by completing multiple shorter sets (i.e., 3 x 30 seconds), appear to increase flexibility of the hip [4], knee [6], and ankle [5]. In addition, one study using roller massage, a similar technique to FR, reported isometric maximal voluntary contraction (MVC) torque increased in the tibialis anterior [16]. Mechanisms proposed to explain the increased joint flexibility are the generation of heat caused by the friction created during FR, and the application of mechanical stress from FR onto the fascia [17]. This might cause the fascia to change from a more viscous and solid resting state, into a compliant state that promotes greater flexibility [17]. In addition, FR might cause phosphorylation of the myosin regulatory light chains, providing a potential mechanism that explains the observed increase in MVC torque [16]. Importantly, following 20 minutes of inactivity, acute improvements in ankle dorsiflexion have been reported to remain above controls performing no FR [5]. Therefore, performing FR totaling ≥90 seconds has been shown to elicit benefits, such as enhanced flexibility, which persist between the warmup and start/restart of competition. The ecological validity of spending ≥90 seconds per muscle group in a time constrained warmup however remains questionable. Nevertheless, it is less known whether the same acute benefits can be elicited with FR durations totaling <90 seconds per muscle group. A review of 73 papers suggests this might be possible, advising that FR for 3 x 30-120 seconds per muscle appears most optimal for increasing flexibility [18]. This is important because understanding the minimal FR duration necessary to induce positive acute effects could assist practitioners to optimize pre-competition and halftime practices.

The acute effects of FR totaling <90 seconds remains equivocal, with little research so far investigating whether <90 seconds can outlast an inactive post-warmup preparatory period. Studies examining both recreational individuals and competitive athletes have highlighted little to no improvement in knee extension or quadriceps flexibility after 60 seconds of FR [11,12], nor superior vertical jump height [2,9,10]. However, within collegiate athletes, hip flexibility significantly increased following 60 seconds of FR [2], and vertical jump height significantly improved following FR totaling 30 seconds [8]. Furthermore, just 10 seconds of roller massage, has been reported to increase sit and reach test performance with no detrimental effect on hamstring MVC torque [19]. Such contradictory findings therefore make the acute effect, and especially the delayed effect beyond any inactive post-warmup preparatory period, of FR totaling <90 seconds inconclusive.

The discrepancies between research implementing shorter durations of FR activity on performance could be attributed to the targeted muscle groups. Research reporting improved flexibility following FR totaling <90 seconds per muscle targeted agonist-antagonist muscle pairs [2], while most studies found little to no effects when targeting only the antagonists [11,12]. The improved flexibility might theoretically have resulted from reciprocal inhibition, a phenomenon whereby targeting agonists results in the inhibition of antagonist motoneurons to increase joint flexibility [20]. This reciprocal inhibition was previously suggested to contribute to improved flexibility following agonist-antagonist FR totaling 180 seconds [3]. Therefore, given the proposed efficacy of agonist-antagonist FR, further investigation is required to establish the effect of shorter FR durations (<90 seconds per muscle), with a specific focus on agonist antagonist muscle pairs. Additionally, despite some studies reporting FR totaling <90 seconds acutely improved vertical jump height [8], it remains unknown if any benefit from FR of reduced durations can outlast a typical inactive post-warmup preparatory period. Therefore, the aim of this exploratory study was to investigate the acute effects of short FR durations on flexibility and vertical jump performance, as well as whether any acute effects could outlast a simulated inactive post-warmup preparatory period of 15 minutes.

METHODS

Design

A repeated measures crossover design was employed (figure 1). Participants completed one familiarization and 3 experimental trials between 1900 and 2030 hours, which were each separated by at least 48 hours rest. Familiarization involved completing one trial utilizing an identical protocol to the experimental trials. Experimental trials began with 5 minutes of jogging at a standardized pace, before a flexibility and vertical jump testing battery (baseline). This testing battery was performed in the fixed order of ankle dorsiflexion range of motion (ADF-ROM), sit and reach (S&R) for hip and lower back flexibility, countermovement jump (CMJ), and squat jump (SJ). Such fixed ordering adhered to recommendations from the National Strength and Conditioning Association to perform flexibility testing before vertical jump testing [21]. Participants were then randomized into 3 groups that performed total FR durations of 0 (control), 30 (30 FR), or 60 seconds (60 FR) in a counterbalanced order across the experimental trials. The testing battery was then immediately repeated to identify any acute effects of FR (acute), which was then followed by participants remaining seated for 15 minutes to simulate an inactive post-warmup preparatory period. The testing battery was then repeated immediately after the simulated post-warmup preparatory period (delayed), to establish whether any acute effects from FR could outlast 15 minutes of inactivity. For all testing, the maximum score from 3 recorded attempts was used for statistical analysis.

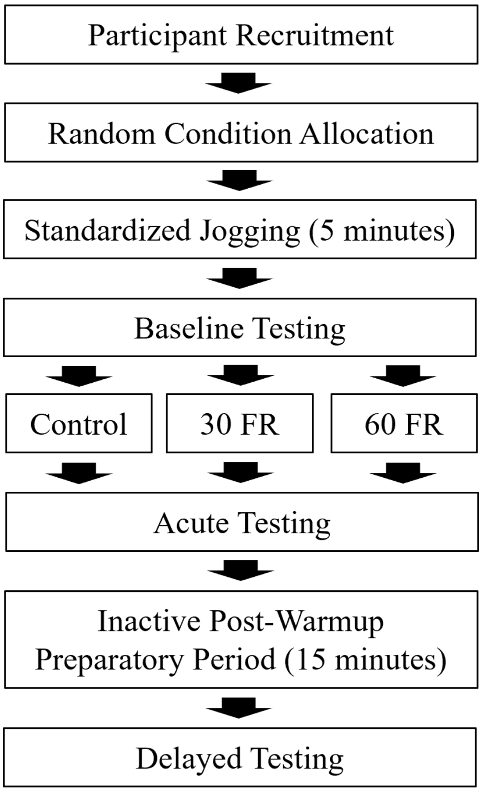

Figure 1. Study flow chart.

Participants

The study received institutional ethical approval from the Northumbria University Health and Life Sciences Research Ethics Committee and was conducted according to the Declaration of Helsinki. After receiving verbal and written explanation of the study, a connivance sample of 11 male athletes (stature 1.77 ± 0.09 m, body mass 78.0 ± 17.0 kg, age 22 ± 2 years, ≥ 6 months amateur boxing experience) provided their written informed consent to take part. All participants had no current lower extremity injury nor any experience of undertaking structured FR. Participants also completed current UK physical activity guidelines of at least 150 minutes moderate or 75 minutes vigorous weekly aerobic activity [22]. This physical activity included averaging at least two boxing training sessions each month, but participants did not perform structured resistance training.

Procedures

All groups performed an initial warmup of jogging around a 10 meters^2 (m^2) square marked out with cones for 5 minutes. The speed was standardized by an online metronome (8notes.com, Red Balloon Technology Ltd, St Albans, UK) to 132 beat/min, by instructing participants to coincide their steps with the beat.

Following the initial warmup, 3 attempts at each baseline flexibility and vertical jump test were performed. All measures of flexibility were performed wearing no footwear, and vertical jump tests were completed in the same footwear between trials. The ADF-ROM test was performed from a standing position. To perform this, participants placed their longest toe, either the hallux or second toe, against a wall and then flexed the corresponding knee until it contacted the wall

[23]. The longest toe was then moved progressively further away from the wall until the knee could not flex for the patella to touch the wall. The furthest distance between the longest toe and the wall, where knee flexion could still enable the patella to touch the wall, was measured to the nearest 0.1 centimeter (cm). This was done using an inextensible tape measure placed perpendicular to the wall, with all readings taken from the most distal aspect of the longest toe. Attempts were excluded if the participants heel lifted off the floor. For the S&R test, participants placed their feet at the base of a S&R box (Cranlea, Birmingham, UK). Whilst keeping both knees extended, participants reached forward with interlocking hands. Both hip and spinal flexion were permitted, with the furthest distance reached then recorded to 0.5 cm [24].

Vertical jump testing was measured to 0.1 cm using the flight time method of an Opto Jump (Microgate, Bolzano, Italy), which was connected to a laptop computer (Idea Pad 510, Lenovo, North Carolina, USA) running Opto Jump Next (Microgate, Bolzano, Italy). Participants started with their feet approximately shoulder width apart and hands placed on hips. During the CMJ, participants squatted to a self-selected depth (established during familiarization) before immediately jumping vertically for maximum height. For the SJ, participants squatted to a 90° knee angle that was measured by a goniometer (Cranlea, Birmingham, UK) approximately using the lateral malleoli and greater trochanter. This position was held for 3 seconds, before jumping vertically for maximum height. During both CMJ and SJ jumps, participants were instructed to maintain knee and hip extension during flight, with slight knee and hip flexion permitted upon landing. Participants were also verbally instructed to "jump as high as possible" and a concrete floor was used for both jumps. Jumps were excluded if the participant's hands did not remain on hips, or flexion of the hips or knees occurred during the flight phase. SJ attempts were also excluded if the participant performed a slight countermovement prior to take off.

Following the initial warmup, baseline flexibility, and vertical jump tests, FR conditions were performed with a Grid Foam Roller (Trigger Point, Porcheville, France) targeting muscles in the fixed order of left then right gastrocnemius, hamstrings, quadriceps, and tibialis anterior. Muscles were targeted unilaterally, with the non-targeted limb being placed above the targeted limb to maximize compression. During FR, participants placed both hands on the floor for stability, and moved their body forwards and backwards over the foam roller. This movement speed was standardized by the online metronome to 40 beat/minutes and the participants were encouraged to maintain their full body mass over the foam roller whilst performing FR. The 30 FR condition involved two sets of 15 seconds per muscle (4 minutes total FR), while the 60 FR condition involved two sets of 30 seconds per muscle (8 minutes total FR). The control condition involved participants remaining seated for 10 minutes.

The reliability of each test was determined prior to formal testing during a pilot study (Table 1). 6 male participants (height 1.74 ± 0.11 m, body mass 75.3 ± 10.5 kg, age 25 ± 8 years), completed 2 trials separated by 48 hours. These trials involved completing 5 minutes of standardized jogging and then one testing battery, both using identical procedures as described above for ADF-ROM, S&R, CMJ, and SJ. Test-retest reliability was then determined through calculating typical error as the standard deviation of the difference score between trials divided by the square root of 2 [25].

Table 1. Inter-trial typical error for each test determined from 2 trials separated by 48 hours inactivity, as well as group averages from each trial.

Test	Trial 1 (cm)	Trial 2 (cm)	Inter-Trial TE (cm)
ADF-ROM distance	9.3 ± 3.8	9.7 ± 3.2	1.8
S&R distance	20.8 ± 5.1	19.4 ± 6.4	1.5
CMJ height	31.8 ± 7.7	33.7 ± 6.5	1.4
SJ height	30.4 ± 6.8	30.6 ± 4.7	1.7

Note. Trial 1 and 2 values are *M* ± *SD*, TE = typical error, ADF-ROM = ankle dorsiflexion range of motion, S&R = sit and reach, CMJ = countermovement jump, SJ = squat jump.

Statistical Analyses

Statistical analyses were conducted using SPSS (SPSS Statistics v26, IBM, New York, USA), with significance set at $p < 0.05$. Normal distribution of data was confirmed using the Kolmogorov–Smirnov test. A paired sample t-test identified no difference between the left and right leg ADF-ROM at baseline ($p = 0.65$). As a result, the mean of the right and left leg was used during subsequent analysis. Sphericity was assessed using Mauchly's test, with non-violations interpreted using assumed sphericity and violations interpreted with Greenhouse-Geisser corrections. A two-way repeated measures analysis of variance was then used to identify a significant interaction effect between FR condition (30 FR, 60 FR, control) and timepoint (baseline, acute, delayed). Where a significant interaction effect was detected, *post hoc* analysis using least significant difference was performed and a 95% confidence interval (CI) calculated. Effect size was also determined for any significant interaction effects using Hedge's *g*, which were categorized as <0.2 trivial, 0.2-0.6 small, 0.6-1.2 moderate, 1.2-2.0 large, 2.0-4.0 very large, and >4.0 extremely large [26]. All data is presented as *M* ± *SD* difference, *f* value, *p* value, 95% CI, and *g*.

RESULTS

No significant FR condition x timepoint interaction effect was detected for the ADF-ROM distance ($f = 1.63$, $p = 0.19$), S&R distance ($f = 0.80$, $p = 0.54$), CMJ height ($f = 0.83$, $p = 0.99$), or SJ height ($f = 0.66$, $p = 0.99$; figure 2/table 2). There was also no FR condition effect measured across all timepoints for either the ADF-ROM distance ($f = 2.00$, $p = 0.16$), S&R distance ($f = 0.01$, $p = 0.99$), CMJ height ($f = 0.22$, $p = 0.80$), or SJ height ($f = 1.05$, $p = 0.37$; figure 2/table 2).

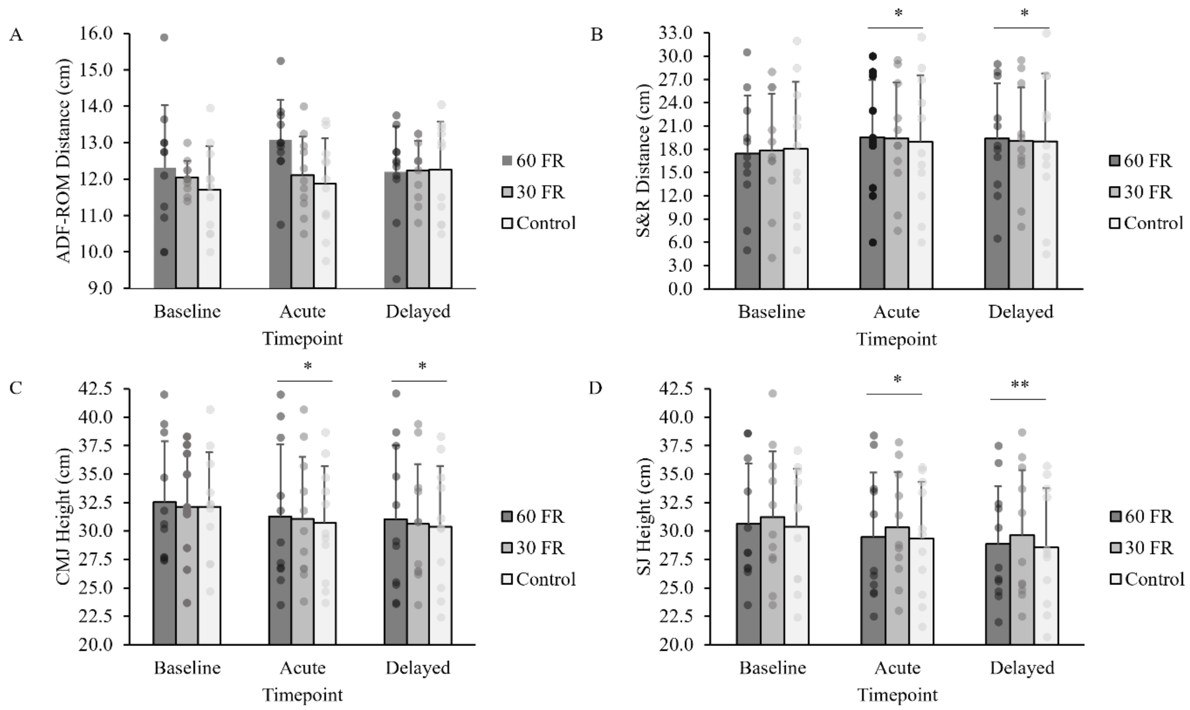

Figure 2. Effects of 60 seconds (60 FR), 30 seconds (30 FR) and no FR (control) on 11 male athlete's flexibility and jump performance. Participants performed measures of ankle dorsiflexion range of motion (ADF-ROM), sit and reach (S&R), countermovement jump (CMJ), and squat jump (SJ), prior to FR (baseline), immediately following FR (acute), and following 15 minutes of inactivity (delayed). Error bars = *M* ± *SD*. * = significant time effect versus baseline. ** = significant time effect versus baseline and acute.

Table 2. Effects of 60 seconds (60 FR), 30 seconds (30 FR) and no FR (control) on 11 male athlete's flexibility and jump performance.

Test	60 FR (cm)			30 FR (cm)			Control (cm)		
	B	A	D	B	A	D	B	A	D
ADF-ROM distance	12.3 ± 1.7	13.1 ± 1.1	12.2 ± 1.2	12.1 ± 0.5	12.1 ± 1.1	12.2 ± 0.8	11.7 ± 1.2	11.9 ± 1.3	12.3 ± 1.3
S&R distance	17.5 ± 7.5	19.5 ± 7.4	19.4 ± 7.1	17.8 ± 7.4	19.4 ± 7.2	19.0 ± 6.9	18.0 ± 8.6	19.0 ± 8.6	19.0 ± 8.8
CMJ height	32.5 ± 5.4	31.3 ± 6.3	31.0 ± 6.5	32.1 ± 4.6	31.1 ± 5.5	30.6 ± 5.3	32.1 ± 4.8	30.7 ± 5.0	30.4 ± 5.3
SJ height	30.6 ± 5.3	29.5 ± 5.6	28.9 ± 5.1	31.2 ± 5.8	30.3 ± 4.9	29.6 ± 5.7	30.4 ± 5.1	29.3 ± 5.0	28.6 ± 5.2

Note. Values are *M* ± *SD*, ADF-ROM = ankle dorsiflexion range of motion, S&R = sit and reach, CMJ = countermovement jump, SJ = squat jump.

No significant main effect was detected for the ADF-ROM distance ($f = 2.32$, $p = 0.13$) across all FR conditions, significant time effects were detected for the S&R distance ($f = 6.58$, $p = 0.02$), CMJ height ($f = 18.33$, $p = 0.01$), and SJ height ($f = 27.89$, $p = 0.01$, figure 2/table 2).

Significant increases in S&R distance of trivial effect size were detected across all 3 FR conditions from baseline to acute (1.5 ± 0.1 cm, p = 0.03, 95% CI [0.2, 2.8] cm, g = 0.19) and from baseline to delayed (1.4 ± 0.2 cm, p = 0.02, 95% CI [0.2, 2.5] cm, g = 0.18). These increases did not however exceed inter-trial typical error, which reduces the certainty that they are meaningful. In addition, no significant difference was detected across all 3 FR conditions from acute to delayed (0.2 ± 0.1 cm, p = 0.46, 95% CI [-0.2, 0.6] cm, g = 0.02).

Significant decreases in CMJ height, of small effect, occurred across all FR conditions from baseline to acute (-1.2 ± 0.7 cm, p = 0.01, 95% CI [-0.5, -2.0] cm, g = 0.24) and from baseline to delayed (-1.6 ± 0.8 cm, p = 0.01, 95% CI [-1.0, -2.2] cm, g = 0.30). No significant difference was also detected across all 3 FR conditions between acute and delayed (-0.3 ± 0.1 cm, p = 0.24, 95% CI [-0.8, 0.5] cm, g = 0.06). Likewise, significant decreases in SJ height, of small effect, were detected from baseline to acute (-1.0 ± 0.2 cm, p = 0.01, 95% CI [-0.6, -1.5] cm, g = 0.20) and from baseline to delayed (-1.7 ± 0.0 cm, p = 0.01, 95% CI [-1.1, -2.4] cm, g = -0.32). A further significant, trivial, decrease in SJ height was also detected between acute and delayed (-0.7 ± 0.2 cm, p = 0.01, 95% CI [-0.2, -1.2] cm, g = 0.13). Only the mean CMJ decrease from baseline to delayed was above inter-trial typical error, questioning whether the other significant decreases in CMJ and SJ height can be considered meaningful.

DISCUSSION

This study investigated the acute effects of FR durations totaling 30 and 60 seconds on flexibility and vertical jump performance, and whether any detected acute effects could outlast a simulated inactive post-warmup preparatory period. The key findings were that, despite targeting agonist-antagonist muscle pairs, neither 30 FR or 60 FR induced any differential effects on flexibility or jump performance when compared to no FR.

It has previously been suggested that discrepancies between previous literature, which have reported no effect [11,12] or a positive effect [2] of short duration (<60 seconds) FR on flexibility, might be attributable to differences in FR protocols. Specifically, some of these studies have targeted muscles in isolation [11,12] rather than agonist-antagonist muscle groups [2]. It has previously been hypothesized that targeting agonist-antagonist muscle pairs might potentially increase flexibility via inducing reciprocal inhibition [3]. However, despite targeting lower body agonist-antagonist muscle groups, the current study reported no effect of 30 FR or 60 FR on ADF-ROM or S&R, which contrasts with previous findings [2]. Interestingly, compared to the current study, previous research utilized a textured foam roller (The Rumble Roller) with raised nodules that is thought to stimulate deeper layers of muscle tissue [2]. Therefore, future research should establish whether the type of foam roller, and therefore the depth of FR, might influence the acute effects induced by FR totaling 30-60 seconds. Although conflicting findings exist [2,27], a recent systematic review of 14 studies observed that higher density foam rollers appear to increase flexibility greater than softer density foam rollers due to increased compression of the fascia [7]. Likewise, the compressive forces induced by FR increase when participants body mass is higher compared to lower, and the device moves proximally compared to distally.[12,28] Future research should therefore perform FR with force plates to further quantify these forces and compare inter-participant differences.

The finding that neither CMJ or SJ height increased following 30 FR or 60 FR within the current study, concur with previous studies who report no increase in CMJ height following FR totaling 30-60 seconds, when compared to controls [2,9,10]. Specifically, other research reported no difference in CMJ height were reported following FR totaling 60 seconds in comparison to dynamic stretching or no treatment conditions [2]. Additionally, no improvement in CMJ height was noted after FR totaling 30 seconds versus controls performing planking exercises [9], or in comparison to controls mimicking FR movements on skateboards [10]. Interestingly, research reporting unchanged CMJ height investigated FR in isolation, without any additional warmup activities [2,9,10], whereas research reporting increased vertical jump height combined FR with dynamic stretching [8]. It has been reported that performing FR totaling 60 seconds, without any other additional warmup activities, resulted in no increase in muscle temperature or muscle contractility (tensiomyography) [12]. Although the current study did not investigate the mechanisms behind isolated FR, it is known that an increase in muscle temperature correlates positively with force production [29]. Therefore, it can be speculated that the duration of FR activity, performed in isolation, within the current study might not have been long enough to increase muscle temperature and enhance CMJ and SJ height. Thus, future research could investigate if the mechanisms that underpin isolated FR are influenced by duration.

Although the current study did detect significant time effects for S&R distance, CMJ height, and SJ height, irrespective of FR condition, these findings should be interpreted cautiously. This is because the means of all, but one detected effect were less than typical error, implying that most of these detected effects were below the test's measurement error. Specifically, after applying typical error, only the mean CMJ decrease from baseline to delayed appears above the measurement error. In contrast, neither the mean CMJ height decrease between baseline and acute timepoints, nor any of the S&R increases or SJ decreases detected across timepoints were above typical error. It should also be noted that, although a repeated measures crossover design was utilized, a relatively small convenience sample was used. These findings should therefore be interpreted with caution until further research can be competed.

To independently identify the effect of FR activity the current study investigated FR in an isolated context, however it should be noted that other activities would typically be included within a well-structured warmup prior to sporting competition [30]. These would likely include dynamic stretches, as well as higher intensity sport specific exercises that could influence subsequent competitive performance [30]. Albeit limited, previous research has reported that when 30 seconds of FR is combined with dynamic stretching vertical jump height is enhanced [8]. Consequently, further research is required to establish whether, when integrated as part of a traditional warmup, performing FR for shorter durations might enhance performance and outlast the post-warmup preparatory period. In addition, it also remains the case that a sporting warmup must prepare the athlete psychologically for the demands of subsequent competition [31]. The psychological effects from FR were not investigated in the current study and have also so far received limited attention within the literature. Although not utilizing FR, research investigating stretching found that participants believed their flexibility and vertical jump performance would increase after either static or dynamic stretching, despite no physiological effect on flexibility or muscle function subsequently being detected [32]. Consequently, this warrants investigation in future research because any positive psychological findings could provide an alternative rational for including short duration FR within a sporting warmup. Finally, only jump height was used as a measure of CMJ and SJ performance because of the applied nature of the research using an Opto Jump. Future research should utilize a force plate to analyze additional metrics like changes in displacement, time to take off and impulse as these may indicate difference in jump strategy occurring following FR.

CONCLUSION

In conclusion, FR durations totaling 30 or 60 seconds, targeting agonist-antagonist muscle pairs, demonstrated no increase in measures of flexibility or vertical jump performance beyond those achieved by an inactive control condition. The inclusion of such short durations of FR within a warmup therefore remains questionable and requires further investigation before clear guidelines can be devised.

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REFERENCES

1. Barnes MF. The basic science of myofascial release: morphologic change in connective tissue. *Journal of Bodywork and Movement Therapies*. 1997;1(4):231-238. https://www.sciencedirect.com/science/article/abs/pii/S1360859297800514

2. Behara B, Jacobson BH. Acute effects of deep tissue foam rolling and dynamic stretching on muscular strength, power, and flexibility in division linemen. *Journal of Strength and Conditioning Research*. 2017;31(4):888-892. https://journals.lww.com/nsca-jscr/pages/articleviewer.aspx?year=2017&issue=04000&article=00003&type=Fulltext

3. Cavanaugh MT, Aboodarda SJ, Hodgson DD, Behm DG. Foam rolling of quadriceps decreases biceps femoris activation. *Journal of Strength and Conditioning Research*. 2017;31(8):2238-2245. https://journals.lww.com/nsca-jscr/fulltext/2017/08000/Foam_Rolling_of_Quadriceps_Decreases_Biceps.23.aspx

4. Junker DH, Stoggl T l. The foam roll as a tool to improve hamstring flexibility. *Journal of Strength and Conditioning Research*. 2015;29(12):3480-3485. https://journals.lww.com/nsca-jscr/fulltext/2015/12000/The_Foam_Roll_as_a_Tool_to_Improve_Hamstring.28.aspx

5. Kelly S, Beardsley C. Specific and cross-over effects of foam rolling on ankle dorsiflexion range of motion. *International Journal of Sports Physical Therapy*. 2016;11(4):544-551. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4970845/

6. MacDonald GZ, Penney MDH, Mullaley ME, et al. An acute bout of self-myofascial release increases range of motion without a subsequent decrease in muscle activation or force. *Journal of Strength and Conditioning Research*. 2013;27(3):812-821. https://journals.lww.com/nsca-jscr/Fulltext/2013/03000/Article.34.aspx

7. Cheatham SW, Kolber MJ, Cain M, Lee M. The effects of self-myofascial release using a foam roll or roller massager on joint range of motion, muscle recovery, and performance: A systematic review. *International Journal of Sports Physical Therapy*. 2015;10(6):827-838. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4637917/

8. Peacock CA, Krein DD, Silver TA, Sanders GJ, von Carlowitz K-PA. An acute bout of self-myofascial release in the form of foam rolling improves performance testing. *International Journal of Exercise Science*. 2014;7(3):202-211. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4831860/

9. Healey KC, Hatfield DL, Blanpied P, Dorfman LR, Riebe D. The effects of myofascial release with foam rolling on performance. *Journal of Strength and Conditioning Research*. 2014;28(1):61-68. https://journals.lww.com/nsca-jscr/fulltext/2014/01000/the_effects_of_myofascial_release_with_foam.8.aspx

10. Jones A, Brown LE, Coburn JW, Noffal GJ. Effects of foam rolling on vertical jump performance. *International Journal of Kinesiology and Sports Science*. 2015;3(3):38-42. http://www.journals.aiac.org.au/index.php/IJKSS/article/view/1811

11. Miller JK, Rockey AM. Foam rollers show no increase in the flexibility of the hamstring muscle group. *UW-LJournal of Undergraduate Research*. Published online 2006:1-4.

12. Murray AM, Jones TW, Horobeanu C, Turner AP, Sproule J. Sixty seconds of foam rolling does not affect functional flexibility or change muscle temperature in adolescent athletes. *International Journal of Sports Physical Therapy*. 2016;11(5):765-776. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5046970/

13. Wiewelhove T, Döweling A, Schneider C, et al. A meta-analysis of the effects of foam rolling on performance and recovery. *Frontiers in Physiology*. 2019;10:1-15. https://www.frontiersin.org/articles/10.3389/fphys.2019.00376/full?fbclid=IwAR1wMoGkHgXUIN12UUf3VnpnaT715kT0R8loil6THZt0Bt4zTJukl28Jzqw

14. West DJ, Dietzig BM, Bracken RM, et al. Influence of post-warm-up recovery time on swim performance in international swimmers. *Journal of Science and Medicine in Sport*. 2013;16(2):172-176. https://www.sciencedirect.com/science/article/abs/pii/S144024401200120X

15. Mohr M, Krustrup P, Nybo L, Nielsen JJ, Bangsbo J. Muscle temperature and sprint performance during soccer matches–beneficial effect of re-warm-up at half-time. *Scandinavian Journal of Medicine and Science in Sports*. 2004;14(3):156-162. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1600-0838.2004.00349.x

16. Halperin I, Aboodarda SJ, Button DC, Andersen LL, Behm DG. Roller massager improves range of motion of plantar flexor muscles without subsequent decreases in force parameters. *The International Journal of Sports Physical Therapy*. 2014;9(1):92-102. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3924613/

17. Paolini J. Review of myofascial release as an effective massage therapy technique. *International Journal of Athletic Therapy and Training*. 2009;14(5):30-34. https://journals.humankinetics.com/view/journals/ijatt/14/5/article-p30.xml

18. Behm DG, Alizadeh S, Anvar SH, et al. Foam Rolling Prescription: A Clinical Commentary. *Journal of Strength and Conditioning Research*. 2020;34(11):3301-3308. https://journals.lww.com/nsca-jscr/Fulltext/2020/11000/Foam_Rolling_Prescription__A_Clinical_Commentary.35.aspx

19. Sullivan KM, Silvey DBJ, Button DC, Behm DG. Roller-massager application to the hamstrings increases sit-and-reach range of motion within five to ten seconds without performance impairments. *International Journal of Sports Physical Therapy*. 2013;8(3):228-236. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3679629/

20. Day BYBL, Marsden CD, Obesot JA, Rothwell JC. Reciprocal Inhibition Between the Muscles of the Human Forearm. *The Journal of Physiology*. 1984;349(1):519-534. https://physoc.onlinelibrary.wiley.com/doi/abs/10.1113/jphysiol.1984.sp015171

21. McGuigan M. Principles of Test Selection and Administration. In: Haff GG, Triplett NT, eds. *Essentials of Strength Training and Conditioning*. 4th ed. Human Kinetics; 2015:249-258.

22. Hunter RF, Tully MA, Donnelly P, Stevenson M, Kee F. Knowledge of UK physical activity guidelines: Implications for better targeted health promotion. *Preventive*

Medicine. 2014;65:33-39. https://www.sciencedirect.com/science/article/abs/pii/S0091743514001479

23. Powden CJ, Hoch JM, Hoch MC. Reliability and minimal detectable change of the weight-bearing lunge test: a systematic review. *Manual Therapy*. 2015;20(4):524-532. https://www.sciencedirect.com/science/article/abs/pii/S1356689X15000065

24. Liemohn W, Sharpe GL, Wasserman JF. Criterion related validity of the sit-and-reach test. *Journal of Strength and Conditioning Research*. 1994;8(2):91-94. https://journals.lww.com/nsca-jscr/abstract/1994/05000/criterion_related_validity_of_the_sit_and_reach.6.aspx

25. Hopkins WG. Measures of reliability in sports medicine and science. *Sports Medicine*. 2000;30(1):1-15. https://link.springer.com/article/10.2165/00007256-200030010-00001

26. Hopkins WG. Linear models and effect magnitudes for research, clinical and practical applications. *Sportscience*. 2010;14:49-59.

27. Yanaoka T, Yoshimura A, Iwata R, Fukuchi M, Hirose N. The effect of foam rollers of varying densities on range of motion recovery. *Journal of Bodywork and Movement Therapies*. 2021;26:64-71.

28. Baumgart C, Freiwald J, Kühnemann M, Hotfiel T, Hüttel M, Hoppe MW. Foam rolling of the calf and anterior thigh: Biomechanical loads and acute effects on vertical jump height and muscle stiffness. *Sports*. 2019;7(1):1-10. doi:10.3390/sports7010027

29. Bergh U, Ekblom B. Influence of muscle temperature on maximal muscle strength and power output in human skeletal muscles. *Acta Physiologica Scandinavica*. 1979;107(1):33-37. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1748-1716.1979.tb06439.x

30. Bishop D. Warm up II: Performance changes following active warm up and how to structure the warm up. *Sports Medicine*. 2003;33(7):483-498. https://link.springer.com/article/10.2165/00007256-200333070-00002

31. Jeffreys I. Warm up revisited–the 'ramp' method of optimising performance preparation. *Professional Strength and Conditioning*. 2006;6(1):15-19.

32. Blazevich AJ, Gill ND, Kvorning T, et al. No effect of muscle stretching within a full, dynamic warm-up on athletic performance. *Medicine and Science in Sports and Exercise*. 2018;50(6):1258-1266.